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The Edinburgh-Cape Blue Object Survey – V. The end: Partial Zones 4–6; Galactic latitudes $-50° > b > -90°$

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ABSTRACT

Results for the remaining zones of the Edinburgh-Cape (EC) Blue Object survey are presented. These are incomplete, but lie in that part of the South Galactic Cap between 50° and 90° from the Galactic plane and south of about $-12\overset{\circ}{.}3$ of declination. This part of the survey comprises 79 UK Schmidt Telescope fields covering about 2150 deg^2, in which we find 536 blue objects – including hot subdwarfs (∼33 per cent), white dwarfs (∼30 per cent), binaries (∼12 per cent), cataclysmic variables (∼1.5 per cent) and some 'star-like' galaxies (∼12 per cent). A further 254 stars observed in the survey, mainly low-metallicity F- and G-type stars, are also listed. Low-dispersion spectroscopic classification is given for all the hot objects and *UBV* photometry for most of them. Either spectroscopy or photometry is listed for the cooler types.

Key words: surveys – stars: early-type – stars: horizontal branch – subdwarfs – white dwarfs – quasars: general.

1 INTRODUCTION

The Edinburgh-Cape (EC) Blue Object survey was conceived in the late 1980s as a way of finding new southern evolved hot stars – subdwarf and white dwarf stars and cataclysmic variables – for detailed study. A description of the survey aims and methods was given by Stobie et al. (1997b, hereafter Paper I) and at the same time the first EC zone was published – the North Galactic Cap south of declination $-12\overset{\circ}{.}3$ (Kilkenny et al. 1997b, hereafter Paper II). More recently, we have produced Zones 2 and 3 of the survey – strips of the South Galactic Cap south of declination $-12\overset{\circ}{.}3$ and between Galactic latitudes $-30° > b > -40°$ (O'Donoghue et al. 2013, hereafter Paper III) and $-40° > b > -50°$ (Kilkenny et al. 2015, hereafter Paper IV). Paper III also contained an assessment of the status of the survey at that time, described some new procedures we have employed, and discussed aspects of the positional and photometric accuracies, for example.

This paper presents results from Zones 4–6 which were originally planned to cover Galactic latitude zones $-50° > b > -60°$, $-60° > b > -70°$ and $-70° > b > -90°$, respectively. Although all the plates were taken, the COSMOS facility was closed down before all could be measured, so that the last three zones are unfinished to the tune of 60 fields (out of 138). Even so, added together Zones 4–6 contain an amount of material comparable to the other zones and we publish all our remaining data here as the final chapter of the survey; Table 1 gives a summary of the results. The cooler F- and G-type stars entered the survey either as a result of errors in the photographic photometry (O'Donoghue et al. 1993) or were bluer than normal because of low metallicities; they have proven to be a useful source of low-metallicity objects.

It is noticeable that the number of hot stars per deg^2 is smaller in this paper than in earlier papers. This is almost certainly due to the fact that hot subdwarfs near the survey limit are several kpc from the Galactic plane and we are therefore – at higher Galactic latitudes – sampling a genuinely decreasing population. This can be seen in fig. 10 of Paper II where the cumulative numbers of hot subdwarfs appear to be levelling off towards the survey limit whereas the extragalactic objects and white dwarfs are still increasing. In the case of the latter, we are still sampling within about 100 pc and therefore within the thick disc. It is also clear from examination of all papers in this series, that the fraction of hot subdwarfs in each sample decreases towards higher Galactic latitudes.

As the survey progressed, we continually worked on the newly discovered hot stars and produced a number of significant results; most notably, the discovery of the first pulsating sdB stars (Kilkenny et al. 1997a; Koen et al. 1997; O'Donoghue et al. 1997;

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Table 1. Summary of EC survey.

Zone	Limits (all $\delta < -12\overset{\circ}{.}3$)	Approx. size (deg^2)	Hot Objects	FG stars
1	$b > +30°$	1560	675	280
2	$-30° > b > -40°$	1730	892	362
3	$-40° > b > -50°$	1400	534	178
4–6	$-50° > b > -90°$	2150	536	254

Table 2. The EC survey – Zones 4–6 UKSTU fields.

Field centres (Declination)	UKSTU fields (West)	UKSTU fields (East)
$-5°$	761	
$-15°$	607–617	674–678
$-20°$	539–543,545–548	601–606
$-25°$	472–476,478–482	532–537
$-30°$	410,413,416,417,419	466–470
$-35°$	358	406
$-40°$	295–297,301,302	345,347,348
$-45°$	242,243	–
$-50°$	195	239
$-55°$	150,151	191,192
$-60°$	115	–
$-65°$	78–80	–

Stobie et al. 1997a). We also found new members of known classes such as the eclipsing, flaring DA+dM binary, EC 13471-1256 (O'Donoghue et al. 2003); a new member of the rare AM CVn variables (O'Donoghue et al. 1994); and several new pulsating DB white dwarf stars (Koen et al. 1995; Kilkenny et al. 2009b; Kilkenny 2016). Studies of particular classes of object have also been published: Chen et al. (2001) reported work on new EC cataclysmic variables; a multiwavelength study was made of EC objects with essentially featureless spectra in the optical region (Sefako et al. 1999); and a study of a significant sample of low-metallicity F- and G-type stars was carried out by Beers et al. (2001). The apparently normal B stars found in the survey were resolved into post-AGB stars (Lynn et al. 2005) and normal B stars at large distances from the Galactic plane (Magee et al. 2001; Lynn et al. 2004), which were additionally used to study the interstellar medium via the Ca II K line (Smoker et al. 2003).

2 ZONES 4–6

The EC survey is limited to plate centres south of declination $\delta = -15°$ and thus to a northern declination limit of about $\delta = -12\overset{\circ}{.}3$. Zones 4–6 are additionally defined by selecting UK Schmidt Telescope (UKST) fields which have centres with Galactic latitudes in the ranges noted in section 1. A list of the UKST fields actually measured is given in Table 2 and the remaining zones are illustrated schematically in Fig. 1. The area of each field measured is $5\overset{\circ}{.}35 \times 5\overset{\circ}{.}35$, but the field centres are 5° apart so that there is a small overlap between adjacent fields. This also means that at the edge of a zone, each field extends a little further than the nominal $2\overset{\circ}{.}5$ from the plate centre. Allowing for this, we estimate that the 79 fields presented here cover about 2150 deg^2.

In the original plan for the EC survey, we had intended to have a Zone 7 which would be an 'equatorial' Zone defined by plate centres $b > 30°$ or $b < -30°$ and $0° > \delta > -10°$. This would have been a substantial overlap with the Palomar–Green (PG) survey (Green, Schmidt & Liebert 1986). The realization that we had to reduce the

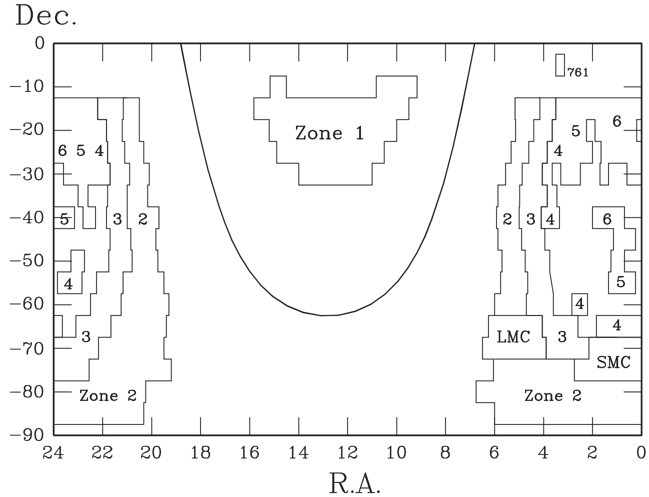

Figure 1. Schematic of the EC survey zones. The solid curved line indicates the Galactic equator. The areas containing the LMC and SMC were explicitly excluded from the survey. Area 761 (top right) is a 'Zone 7' field (see section 2).

amount of work involved together with the fact that there were not big differences between the EC and PG surveys (see Paper I) led to the early removal of this zone from the EC survey. In the meantime, a few plates had been taken and measured, so we included these in the survey papers – a few fields in Zone 1 (see Fig. 1) and field 761 in this paper (see Table 2).

3 RESULTS

The spectroscopic and photometric results from Zones 4–6 of the EC Survey are given in Tables 3 and 4; Table 3 lists the hot objects and Table 4 the cooler objects. As with earlier papers, the tables contain the EC Survey object name, derived from *truncated* 1950.0 coordinates in the format EChhmm.m-ddmm; 1950.0 coordinates; the date of the photometric observations (day/month/year); V, $(B-V)$ and $(U-B)$ data; a spectral type; and any relevant comments. Brief notes on the photometry and spectroscopy are given below; for more detailed descriptions, the reader is referred to Paper III.

3.1 Equatorial coordinates

The 1950.0 equatorial coordinates are determined from COSMOS and SuperCOSMOS measurements and have been quoted as accurate to an arcsecond (Paper I) based on experience with those measuring systems. A comparison given in table 3 of Paper III indicates that the accuracy is certainly not significantly worse than that.

3.2 *UBV* photometry

The photoelectric *UBV* photometry was obtained with the 0.75-m and 1-m telescopes at the Sutherland site of the South African Astronomical Observatory (SAAO). All data were reduced to the Cousins' E-region system (as listed by Menzies et al. 1989). In Paper II (Zone 1), blue extensions to the E-region *UBV* photometry were based on blue star photometry by Menzies, Marang & Westerhuys (1990). However, Kilkenny et al. (1998) showed that

Table 3. Hot objects in Zones 4–6 of the EC survey. This is a small sample of the data; the full table is available online.

EC	α_{1950}	δ_{1950}	Date	V	$(B-V)$	$(U-B)$	Sp.type	Comments
00008-1637	0 00 50.9	−16 37 49	19/09/14	12.68	−0.15	−1.03	sdOB	WD (sdB); hsp; K line?
00008-2355	0 00 48.5	−23 55 40	16/09/93	13.29	−0.26	−0.92	sdB+F	PHL 2580; TonS 135
00009-1700	0 00 58.1	−17 00 41	22/09/14	14.86	0.00		He-sdB	no H; He I weak; WD (sdB)
00019-2443	0 01 57.6	−24 43 03	11/11/91	13.89	−0.27	−1.13	He-sdB+F	TonS 137; PHL 645
00026-2648	0 02 36.4	−26 48 30	11/11/91	15.99	−0.15	−0.99	sdB	TonS 138; PHL 649; (sdB)
00038-1612	0 03 49.4	−16 12 26	16/10/15	16.56	−0.22	−1.18	DA	
00042-2737	0 04 13.4	−27 37 35	11/11/91	13.99	−0.26	−1.11	sdB	TonS 140; PHL 666; (sdB)
00050-1622	0 05 01.6	−16 22 14	16/10/15	16.00	+0.06	−0.78	DA	WD (DA3.4)
00075-2629	0 07 34.5	−26 29 37	16/09/93	12.87	−0.19	−1.14	He-sdB	PHL 703; TonS 144
00082-2054	0 08 13.7	−20 54 59		16.92	0.00	−0.09	DAwk	PHL 712
00088-1245	0 08 52.0	−12 45 26	20/09/14	14.55	−0.23		sdB	
00107-2932	0 10 47.3	−29 32 50	02/12/86	15.35	+0.34	−0.48	eGal	2dFGRS (Sy2)
			25/08/87	15.43	+0.26	−0.36		
00120-5649	0 12 03.6	−56 49 02	27/10/92	16.40	−0.27	−1.01	sdB	hsp
00121-2252	0 12 11.9	−22 52 03	13/10/87	16.36:	+0.18:	−0.71:	AGN	PHL 6933
00130-2601	0 13 03.6	−26 01 59	13/10/87	16.58	−0.29:	−1.15:	sdB	PHL 756; TonS 145
00136-2406	0 13 40.9	−24 06 47	17/10/88	15.37	−0.01	−0.79	DA	PHL 761; TonS 147; WD (DA2.6)
00139-2502	0 13 58.4	−25 02 48	13/10/87	16.84:	−0.10:	−0.87	DA	PHL 675
00141-3143	0 14 10.8	−31 43 38	25/08/87	17.10	−0.07	−0.77	AGN	PHL 2813; VV (QSO)
00163-3212	0 16 22.6	−32 12 43	02/12/86	14.44	−0.15	−1.10	He-sdB	PHL 786: TonS 148
			25/08/87	14.45	−0.16	−1.11		
00166-4340	0 16 37.2	−43 40 58	03/10/92	15.53	+0.12	−0.89	DA	
00169-2205	0 16 56.6	−22 05 44	15/11/93	15.33	+0.12	−0.57	DA	PHL 2856; WD (DA3.7)
00169-3216	0 16 54.0	−32 16 33	26/08/87	15.67	−0.19	−1.14	sdB/DA?	PHL 789; TonS 151
00179-6503	0 17 59.1	−65 03 06	14/07/93	14.36	+0.00	−0.41	HBB/B6	
00190-5545	0 19 02.4	−55 45 50	25/07/92	16.19	−0.30	−1.13	He-sdB?	JL 179; poor spectrogram
00192-6352	0 19 12.9	−63 52 03		16.34	−0.01	−0.09	DA	
00194-2441	0 19 27.6	−24 41 59	17/10/88	14.47	−0.36	−1.22	sdOB	TonS 154; WD (sdB)
00201-3127	0 20 08.8	−31 27 17	12/10/88	16.74	+0.20	−0.77	DA	G267-089
00203-2225	0 20 19.3	−22 25 35		16.62	+0.01	−0.05	DA	
00214-2326	0 21 28.3	−23 26 31	13/10/87	16.03	−0.09	−0.95	sdB+F	TonS 155; WD (sdB)
00227-2107	0 22 45.6	−21 07 58		16.86	+0.01	−0.07	cont ?	6dFGS (Sy1)
00234-2114	0 23 27.3	−21 14 07	20/08/92	13.97	−0.26	−1.10	sdOB	LB7736

Table 4. Cool objects in Zones 4–6 of the EC survey. This is a small sample of the data; the full table is available online.

EC	α_{1950}	δ_{1950}	Date	V	$(B-V)$	$(U-B)$	Sp.type	Comments
00076-1740	0 07 39.2	−17 40 48		∼14.8			F6	
00097-3243	0 09 43.0	−32 43 50	25/08/87	16.38	+0.39	+0.17	F	
00102-2731	0 10 14.0	−27 31 48	13/10/87	15.99	+0.48	−0.08		
00125-4712	0 12 35.8	−47 12 44	03/10/92	13.52	+0.49	−0.07		
00128-4728	0 12 48.8	−47 28 50	03/10/92	14.25	+0.46	−0.25		
00131-1551	0 13 06.5	−15 51 23		∼15.7			G0	
00148-1757	0 14 48.9	−17 57 31		11.48			G3	TYC 5842-841-1
00150-4719	0 15 05.9	−47 19 42	03/10/92	14.32	+0.57	−0.02		
00150-4736	0 15 02.4	−47 36 40	03/10/92	13.76	+0.62	−0.06		
00153-1750	0 15 20.2	−17 50 41		9.46			F4	BD−18°38 (G0)
00160-4703	0 16 02.7	−47 03 19	11/08/92	15.72	+0.45	−0.22		
00174-2151	0 17 24.7	−21 51 21	15/11/93	15.60	+0.59	−0.18		PHL 2863
00201-4741	0 20 09.3	−47 41 32	03/10/92	13.30	+0.49	−0.11		
00230-2340	0 23 05.1	−23 40 45	17/10/88	14.09	+0.59	+0.05	G1	
00272-1621	0 27 15.9	−16 21 32		∼16.5			G1	
00279-1245	0 27 56.1	−12 45 08		14.99	+0.06	−0.01	G0	
00280-1235	0 28 00.5	−12 35 23		14.30	+0.09	+0.07	G1	
00289-1232	0 28 58.8	−12 32 39		15.15	+0.04	−0.01	F7	
00289-1238	0 28 56.8	−12 38 22		14.82	+0.07	−0.01	G2	
00293-1228	0 29 20.3	−12 28 46		14.46	+0.06	−0.04	G1	
00315-2410	0 31 34.3	−24 10 48	01/09/89	13.81	+0.50	−0.04		
00316-2543	0 31 41.2	−25 43 45	01/09/89	14.88	+0.50	−0.06	F5	
00317-2548	0 31 43.9	−25 48 29	30/08/89	15.45	+0.40	−0.14		
00320-2358	0 32 01.6	−23 58 10	30/08/89	15.39	+0.53	−0.17		

there were small differences between the Menzies et al. (1990) photometry and later results. For the Zone 2 and 3 results, we therefore corrected all the pre-1995 data according to the formulae given in sections 6 and 7 of Kilkenny et al. (1998) and we have done the same here. For data obtained since 1995, the reductions were all done directly to the Menzies et al. (1989) standards and the Kilkenny et al. (1998) blue extensions. In Tables 3 and 4, the photoelectric results are those dated earlier than 2003.

We confessed in Paper III to losing some of the original reduced photoelectric photometry from several nights and we have taken the data from our working logs which record online results. These will not have the quality of the finalized measurements and should be treated with appropriate caution. In Tables 3 and 4, such photometry is indicated by the absence of a date of observation.

Additionally, we have been able to obtain *UBV* CCD photometry during two weeks in 2013 September/October and two weeks in 2014 September using the SAAO 1m telescope and STE3 detector, and in one week in 2015 October with the SAAO 1.9-m + new SHOC camera (Coppejans et al. 2013). These measurements were standardized using stars from the same sources as the photoelectric photometry.

Where we have no photometry at all, we have used the SIMBAD data base operated at the Centre de Données astronomiques de Strasbourg (CDS; Wenger et al. 2000) to search for published *V*-magnitudes and have included these in the tables, often with an indication of the source in the 'Comments' column. In the case of Table 4, for example, a number of stars appear in the second reduction of the *Tycho* catalogue (Høg et al. 2000) and where we have extracted a magnitude from that catalogue, the *Tycho* identification is given in the Comments column. (Note that, where we have extracted a *V*-magnitude from SIMBAD, there might well be photometry in other colours available. We have quoted only the *V* so that it is clear it is not our photometry).

If no magnitude could be found by SIMBAD for any star, we have estimated a magnitude by comparing the photographic magnitudes in the field of the star to our photoelectric photometry. Since photographic magnitudes will be much less accurate and since we can not make any colour correction, such magnitudes will be very approximate and are prefixed by a tilde ($\sim$) in Tables 3 and 4.

The referee has noted that a few of the stars which have more than one *UBV* observation show significant differences in the photometry. This is unlikely to be due to observational problems since, for the photoelectric measurements, we used an observing sequence *VBUUBV* on the star, followed by *UBV* on the sky. For the faintest stars, the entire sequence was sometimes repeated two or three times. This has the advantage that the symmetrical observation of the star reduces errors (at least in the colours) if the sky transparency is varying and also allows such variations to be detected easily and the data rejected. Two of the objects, EC 00107-2932 and 02054-2408 show variations in all quantities – V, $(B - V)$ and $(U - B)$; they are extragalactic (eGal and AGN) and might well be variable. We have no further evidence for this, but variability is common amongst such objects (Ulrich, Maraschi & Urry 1997, for example). Three stars, EC 03340-3116, 03094-2730 and 22466-5609 show good agreement in V and $(B - V)$ but poor in $(U - B)$. They are not the bluest stars, with $(B - V) \sim +0.3$ to $+0.5$ and thus have much lower count rates in U than B or V. Even with substantially longer integration times for the U filter, it is impractical to get counts for U which are comparable to B and V. Any $(U - B)$ differences for such stars are thus almost certainly due simply to lower signal at U.

3.3 Spectral types

Low dispersion (100 Å mm^{-1}) spectrograms were obtained for the hot objects and some of the cooler ones using the Unit Spectrograph on the SAAO 1.9-m telescope. Almost all of the work was done with grating 6 which has a coverage about 3600–5400 Å and resolution $\sim$3.5 Å. Prior to 1997, the spectrograph was equipped with a Reticon detector but subsequently has used a CCD detector. Figs 9–14 in Paper I give examples of some of the Reticon spectra. In a few cases, particularly the faintest objects with spectra which appear to show no features in the grating 6 spectrograms, we have also obtained grating 7 data (210 Å mm^{-1}, with a coverage of about 3600–7200 Å and resolution of $\sim$7 Å).

Paper I describes the basis of our classification process, which we have tried to maintain throughout the survey. In brief, we have used the scheme proposed by Moehler et al. (1990) for the hot subdwarf stars and blue horizontal-branch stars. Additionally, since our spectra extend to well below the Balmer discontinuity, the latter has been a useful classification indicator. In the hot subdwarfs, the Balmer lines are usually seen only to about n = 10–12, whereas in normal B stars, they are often visible to n = 13 or 14. The horizontal-branch B stars (HBB) might have even more lines visible; the white dwarfs will typically have far fewer visible lines, only to about n = 8. The white dwarf stars are generally easy to classify in broad terms because of their massively Stark-broadened (very high gravity) spectral features and we have followed the scheme described by Sion et al. (1983) with the well-known types, DA, DB, and so on.

Extragalactic objects were classified into two groups, based on their general spectral appearance – 'AGN' (active galactic nuclei) for objects which show significant continuum flux with broad and usually strong emission features and 'eGal' for objects which show relatively sharp emission features and often little or no continuum flux. We have also used a classification 'cont' for objects which show no clear spectral features other than continuum flux. These might, of course, include Galactic objects (see Sefako et al. 1999).

Cataclysmic variables (generally, objects with strong, non-redshifted emission lines) have been classified 'CV' without any attempt to subdivide, though sometimes we attach a modifying comment in the final column of Table 3.

Apparently normal B, A, F and G stars have been classified by comparison with high signal/noise (S/N) spectrograms of bright stars with well-determined spectral types. We have not attempted luminosity classification.

Composite spectral types have generally been given to objects which show features which are extremely unlikely to arise from a single object. Common amongst our types are 'sdB+F' which will usually denote a spectrum which appears to be an sdB star but which also shows the Ca II K line and perhaps other late-type features; the *G*-band is not unusual. A type 'F+sd' would be given to an F star which had evidence of He I lines.

It was not always easy to decide between types such as normal B stars and blue horizontal-branch stars, or various kinds of hot subdwarf where weak spectral features might be lost in the noise. This has resulted in classifications of the type HBB/B5 or sdB/sdOB where we cannot easily decide between two types; in such cases, we have considered the first classification to be the more likely.

3.4 Comments

The final column of the survey tables contains necessarily brief comments. These fall into four main categories.

(i) Comments on the quality of the photometry or spectroscopy and on particular features – 'He I strong', for example – and indications where variability might be present.

(ii) Comments such as 'hsp' or '2hsp' indicate that 'high-speed' (continuous) photometry has been obtained on one or more occasions. These have a typical resolution of 10–20 s and a time base of 1–2 h. Where any significant variation has been found, a reference is given.

(iii) References from some collaborative projects on apparently normal B stars and cataclysmic variables which give additional photometry, spectroscopy or analyses (temperatures, gravities, abundances, etc.). These references are abbreviated as follows: Ch01 for Chen et al. (2001); Ma98 and Ma01 for Magee et al. (1998, 2001); Ro97 for Rolleston et al. (1997) and Ly04 for Lynn et al. (2004).

(iv) Some alternative designations are listed, including spectral types from the literature, where these are available. We have carried out searches of the SIMBAD data base for correspondences within 10 arcsec of our catalogue positions.

The alternative designations are in no way complete or exhaustive. Some stars, particularly the brighter ones, have many different names, and the available space permits only one or two alternatives. The reader is referred to the SIMBAD data base for a much more complete list of available information. (Of course, for some EC objects even SIMBAD has no data).

Our particular choices for alternatives were based on two main considerations: first, to select sources which contained significant information such as independent spectral types. These sources include the BPS CS stars (Beers, Preston & Schectman 1985), the 6-degree Field Galaxy Survey (6dFGS: Jones et al. 2004), the Hamburg-ESO survey (HE: Wisotzki et al. 1996, for example), the White Dwarf catalogues (WD: McCook & Sion, 1999 – later versions are available on-line) and the catalogues of quasars and AGN (VV: Véron-Cetty & Véron, 2010, for example). We note that these references are sometimes compilations and often not the source of the spectral types. The few HD stars in our table have MK types from the extensive work of the Michigan group (Houk & Cowley 1975; Houk 1978; etc.). For some catalogues, we have not given the star name, only the catalogue abbreviation because the alternative star name is effectively the same as the EC name – based on 1950 coordinates but with differing accuracies. Thus EC 00321-2744 = HE 0032-2744 = WD 0032-277, for example.

Our second consideration was to select alternative designations from surveys which overlapped significantly with ours and were the discovery sources. These include the Luyten Blue (LB) stars (Luyten & Anderson 1958, 1959, 1967); the Palomar–Haro–Luyten (PHL) stars (Haro & Luyten 1962); the Tonantzintla South (TonS) stars (Chavira 1958) and the JL stars (Jaidee & Lyngå 1969). Because the data presented here are from high Galactic latitudes, there is considerable overlap with these older 'Galactic Cap' surveys. Even though these stars have been known to be blue for many decades, there are thousands of them so that many still do not have spectral types or multicolour photometry.

We have not generally referred to data bases from astronomical satellite missions in the tables; there are quite a few EC objects which have been observed by *IUE*, *EUVE*, *GALEX* and so on, as well as many included in the ground-based 2MASS survey, but it would be impossible to include all of these in a systematic and consistent way. As it is generally the actual measurements which are important, the reader is referred to SIMBAD for these data.

Table 5. Numbers/percentages of hot objects in EC Zones 4–6.

Genus	Species	n	per cent
Apparently normal	B	17	3
Horizontal-branch	HBB	18	3
	HBA	2	0.5
Subdwarf	sdB	132	25
	He-sdB	12	2
	sdOB	10	2
	sdO	9	1.5
	He-sdO	16	3
White dwarf	DA	151	28
	Others	13	2
Cataclysmics		7	1.5
Extragalactic	AGN	59	11
	eGal	3	0.5
Binaries	subdwarf +	47	9
	FG +	13	2
	DA+dM	2	0.5
Others	cont	22	4
	others	3	0.5

Table 5 summarizes the statistics of the Zones 4–6 results.

4 TWO-COLOUR DIAGRAMS

In conformity with the earlier zone papers, we present two-colour diagrams for the principal classes of objects found in Zones 4–6.

Fig. 2 shows the apparently normal stars. As noted earlier, the F- and G-type stars were probably included in the survey as the long 'tail' in the error distribution of the photographic photometry or

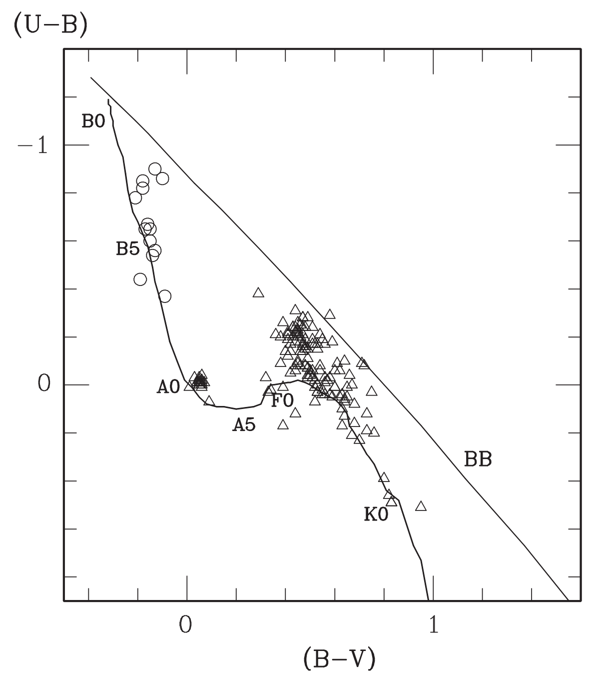

Figure 2. Two-colour diagram for apparently normal stars. Open circles represent B stars; open triangles represent stars of type ∼mid-A and later. The intrinsic colour line is from FitzGerald (1970) and the blackbody line from Straizys, Sudzius & Kuriliene (1976). The approximate locations on the intrinsic colour line of a few typical main-sequence types are indicated.

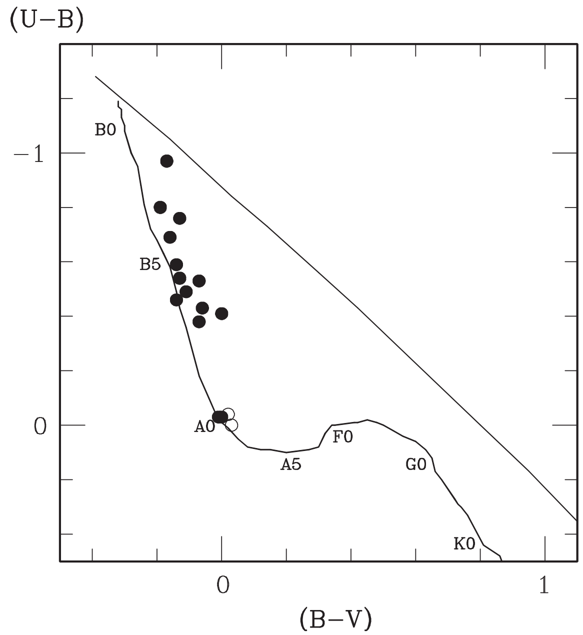

Figure 3. Two-colour diagram for horizontal-branch stars. Solid circles represent stars spectroscopically classified HBB and open circles stars classified HBA. The intrinsic colour and blackbody lines are as for Fig. 2, though the scale and range of this figure are different.

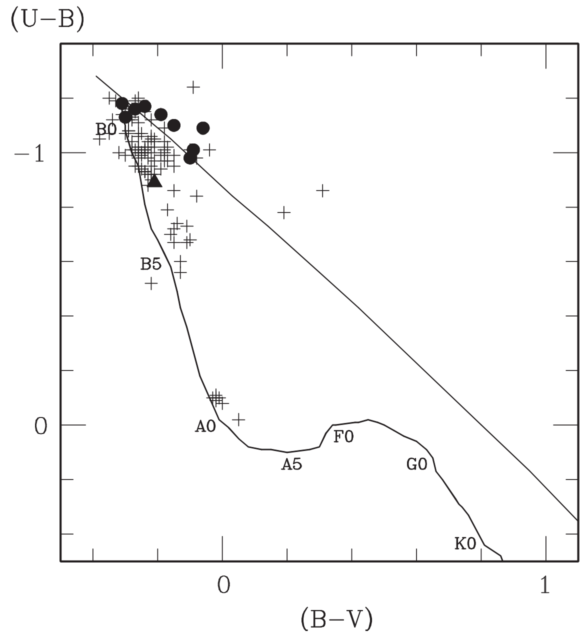

Figure 4. Two-colour diagram for sdB stars. Crosses represent stars classified sdB and filled circles represent stars classified He-sdB. The solid triangle represents EC 03501-3034 (see section 5.4). The intrinsic colour and blackbody lines are as for Fig. 3.

because they are metal-deficient Population II stars. They show the classic distribution of normal FG stars plus late-type subdwarfs – the latter extending above the intrinsic colour line as a result of varying metal-deficiency (Sandage & Luyten 1969).

The early-type stars which look normal spectroscopically, also look photometrically like slightly reddened B stars with equivalent spectral types ~B0 to B9. At the dispersion and typical S/N of our spectra, it is very difficult to distinguish between normal B stars and some horizontal-branch stars; typically, detailed analysis of metal abundances is required to make the distinction (see for example, Magee et al. 2001; Lynn et al. 2004, 2005).

Fig. 3 plots the horizontal-branch stars. The HBB and B stars appear photometrically the same and, as noted above, are often difficult to distinguish spectroscopically.

Figs 4 and 5 show the sdB/He-sdB and sdO/He-sdO/sdOB stars, respectively. A few of these stars are rather redder than might be expected – with colours extending down the blackbody line – and might well be unrecognized binaries (compare with Fig. 6).

Fig. 6 represents the stars with visibly composite spectra – presumably binary systems. These fall into two classes; in the first, the subdwarf is obvious, but late-type features such as Ca II K and perhaps the G band are visible. In the second, the spectrum is clearly of F- or G-type but early-type features (usually He I) are present. The former would generally be bluest and this is clear in Fig. 6. It is unlikely that we have identified all the binaries in the sample; systems comprising a hot subdwarf and a K- or M-type companion would not be detected by us as spectroscopically binary and a single observation per star will not uncover eclipsing or reflection-effect systems.

Fig. 7 plots white dwarf stars and cataclysmic variable systems. The colours of white dwarf stars do lie along the blackbody line and this is not an indicator of binarity. The apparent colours of cataclysmic variables may be affected by strong spectral emission lines.

Finally, Fig. 8 shows the extragalactic objects and spectra for which we can see no clear features ('cont'). The AGN and eGal

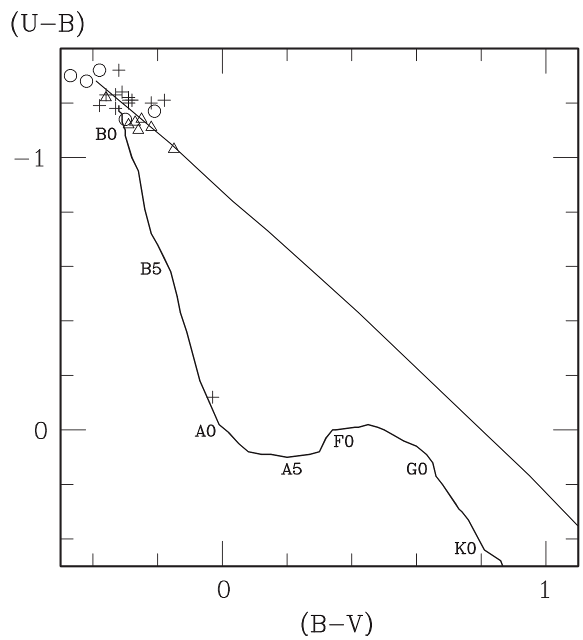

Figure 5. Two-colour diagram for sdO stars. Open circles represent stars classified sdO; crosses represent stars classified He-sdO and triangles represent stars classified sdOB. The intrinsic colour and blackbody lines are as for Fig. 3.

types are scattered in the two-colour diagram and many lie well above the blackbody line – again a result of the interaction of the filter passbands with the relatively strong spectral emission features which can be in different locations, depending on the recession velocity of the object.

It is of perhaps minor interest that each of Figs 3–8 contain a small number of objects with photometry close to spectral type A0, that is,

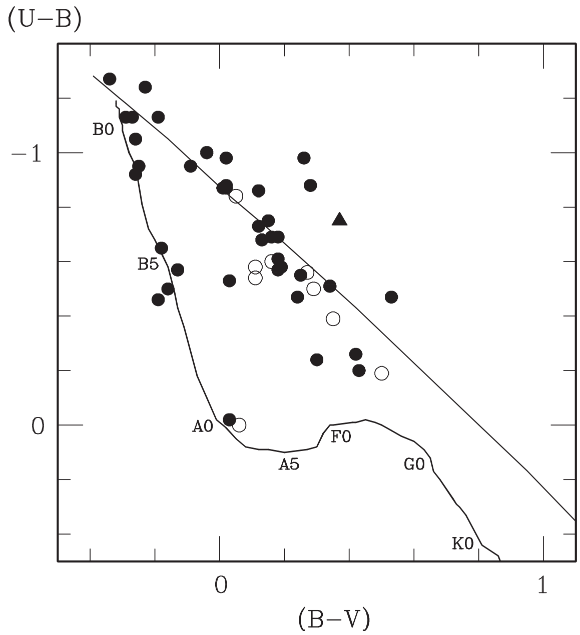

Figure 6. Two-colour diagram for composite stars. Solid circles represent classifications such as sdB+F and sdO+G, where the hot subdwarf dominates the spectrum; open circles represent stars where the cooler star dominates (F5+sd, F+sd? and so on). The filled triangle represents the DA+dM system, EC 03319-3541. The intrinsic colour and blackbody lines are as for Fig. 3.

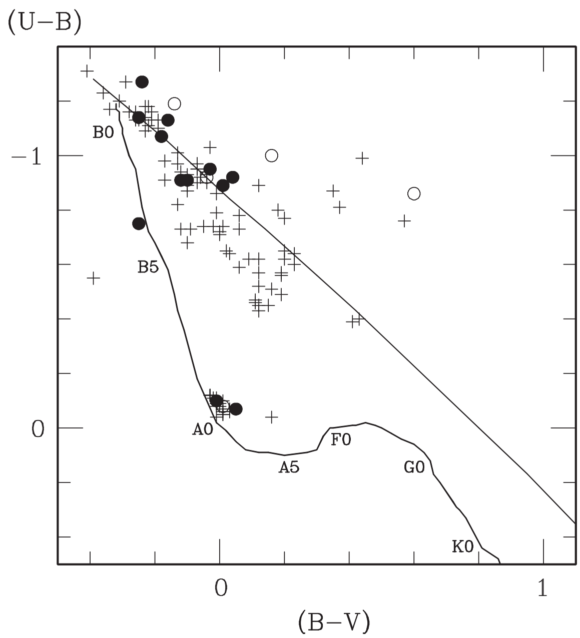

Figure 7. Two-colour diagram for white dwarf stars and cataclysmic variable systems. Crosses represent DA stars; filled circles represent other types of white dwarf – mainly DB stars; open circles represent CV systems. The intrinsic colour and blackbody lines are as for Fig. 3.

around $(B-V)=0$ and $(U-B)=0$. Similar objects are not seen in the earlier papers in this series and, at first, we suspected that errors might have been made in spectral classification. However, several of the objects, particularly the white dwarf stars and AGN, appear in other catalogues with no substantial differences in the classification. We have checked the other objects and see no strong

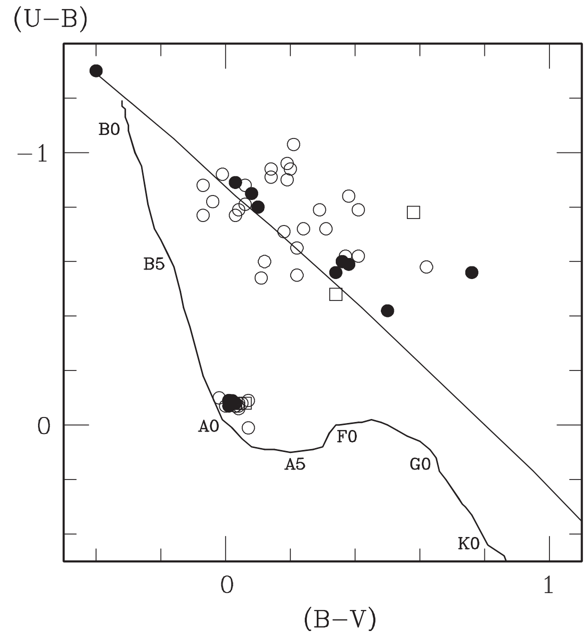

Figure 8. Two-colour diagram for extragalactic objects and for objects which show no discernible spectral features in the range of our spectrograms. Open circles represent objects we have classified 'AGN'; the open squares represent objects we have called 'eGal'; filled circles represent our 'cont' classification. The intrinsic colour and blackbody lines are as for Fig. 3.

reason to change any of our classifications. It is possible that these are undetected binaries – see Fig. 6, where two objects classified as spectroscopically composite lie in this area of the two-colour diagram. It is also possible that we are seeing a selection effect; perhaps at higher Galactic latitudes, our red cut-off – dependent on the first detections of FG-type stars – is somewhat redder than in the early papers. If this is the case, then it is possible that objects with similar colours seen in Fig. 2 could in fact be hot. For these, we would have obtained photometry, assumed the objects were early A stars, and not obtained spectroscopy. In either case, spectral classification of these objects might be worthwhile.

5 COMMENTS ON INDIVIDUAL OBJECTS

5.1 EC 00269-2150

In the spectrum of EC 00269-2150, we see only H α in emission – hence our 'CV?' classification. However, Reimers et al. (1998) noted this object to be a DB white dwarf with a magnetic field of ~20MG. H α emission is also clearly visible in their spectroscopy. The He I lines are split and thus broadened by the magnetic field which makes them difficult to see in our spectrograms. Continuous photometry with a resolution of ~26 s and a baseline ~5000 s shows no obvious sign of variability. There is no peak in the periodogram as large as 0.005 mag; any signal is indistinguishable from noise.

5.2 EC 00497-4723 = CO Phe

EC 00497-4723 is here classified as DA but is already known as a ZZ Ceti star (CO Phe) – a variable DA white dwarf. We can find very little in the literature concerning this star; the most recent paper (Castanheira & Kepler 2009) lists the star with five periods (722, 867, 1083, 1182, and 500 s), citing Stobie et al. (1997c) as

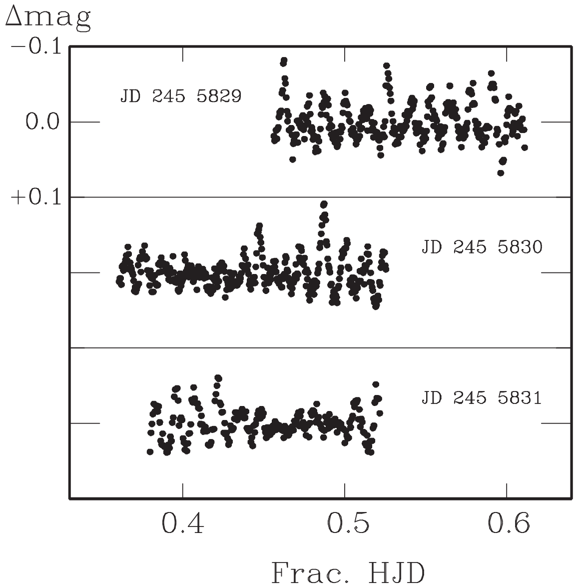

Figure 9. Continuous photometry for EC 00497-4723 on the nights of 2011 Sep 23/24, 24/25 and 25/26.

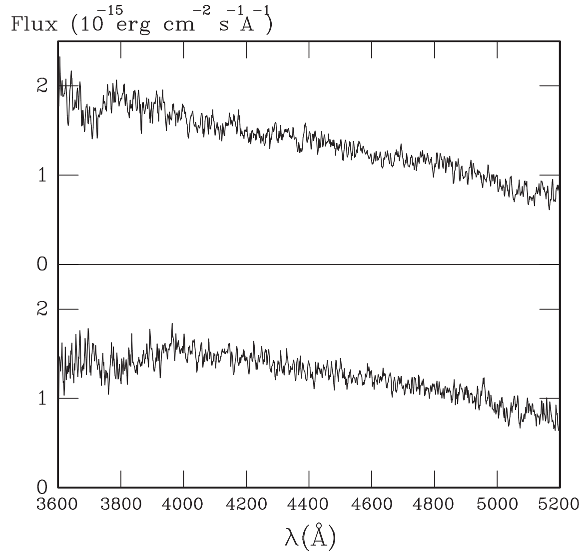

Figure 10. Spectrograms for EC 01302-2759 on the nights 1987 Dec 20/21 and 1989 Dec21/22. These have been smoothed with a five-point running mean in the ratios 1:2:4:2:1.

source but the latter paper, a conference contribution, contains no numerical values for pulsation frequencies.

In an incomplete manuscript, the late Dr R. S. Stobie (1998, unpublished) lists seven periods, only two of which (506 and 727 s) are close to the Castanheira & Kepler (2009) periods. Fig. 9 shows additional observations by one of the current authors (DK); these confirm CO Phe as a complex pulsator and exhibit a dominant period near 845s (amplitude ∼ 0.02 mag) – close to one of Stobie's unpublished periods (844s) – but nothing significant is seen near any of the periods listed by other authors. Stobie analyses longer runs on five nights and notes '... the variations of EC 00497-4723 are clearly complex and highly variable from night to night.'

5.3 EC 01302-2759

This star is not in the WD catalogue but SIMBAD lists an uncertain type of DA: our spectroscopy shows the spectrum to be essentially featureless in the blue (Fig. 10), hence our continuous classification.

5.4 EC 03501-3034

EC 03501-3034 was found to be variable in 2004 (Fig. 11). It is likely to be a close binary system; the obvious period in the light variation is near 7000 s – so the binary period is ∼0.08 d if the effect is due to reflection or ∼0.16 d if it is geometric. The latter is perhaps the least likely because the observed variation has an amplitude of ∼10 per cent, whereas the very blue colours – close to the intrinsic colour line (Fig. 4) – suggest that the secondary does not contribute much to the total light of the system. Radial velocities should resolve this issue.

The spectral type is uncertain; at $V \sim 17.3$ the spectrogram is understandably noisy. The star was classified sdB but later revised to sdB/DAB. Broad Balmer lines are only visible to about $n = 8$, though the poor S/N could mask ultraviolet lines. He I 4471 appears to be present, though He I 4026, if present, is lost in the noise. In either case, the colours indicate that the primary is very hot.

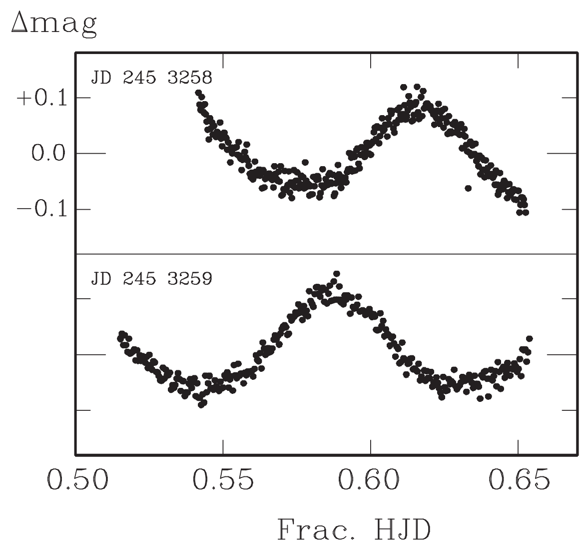

Figure 11. Continuous photometry for EC 03501-3034 on the nights of 2004 Sep 9/10 and 10/11.

5.5 EC 22019-2250

This star has a type DA listed by SIMBAD and a white dwarf designation WD 2201-228 (DAH? DB). Two spectrograms are shown in Fig. 12 which have weak evidence for He I 4026 and 4471 and also Ca II 3933, though the evidence for Ca II 3968 is weaker – and the spectrograms are noisy at the blue end. A lower dispersion spectrogram (210 Å mm^{-1}) extending to about 7000 Å shows evidence for the He I blend near 5875 Å and no sign of H α though, again, the S/N is not great. We have classified the star DBwk, though 'cont' might also be appropriate. Continuous photometry with a resolution of 20 s and a baseline ∼5800 s shows no obvious sign of variability; there is no peak in the periodogram as large as 0.003 mag.

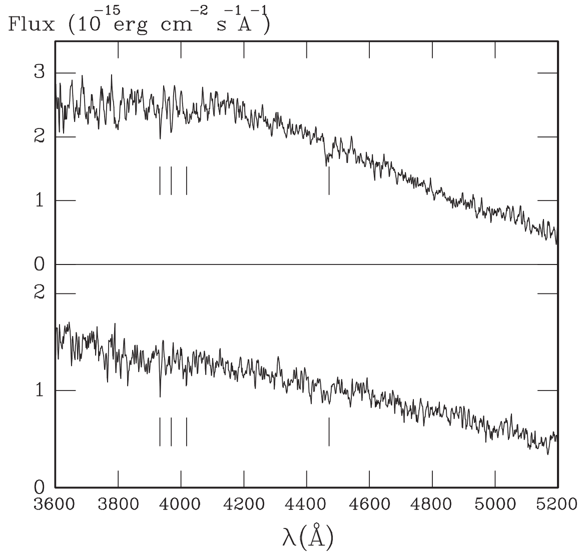

Figure 12. Spectrograms for EC 22019-2250 on the nights 1989 Aug 5/6 and 1991 Oct 10/11. These have been smoothed with a five-point running mean in the ratios 1:2:4:2:1. The short vertical lines indicate the positions of the Ca II 3933 and 3968 (H & K lines) and the He I 4026 and 4471 lines.

6 CONCLUSION

The EC survey is now ended and, although incomplete as originally designed, it has surveyed approximately 6800 deg^2 of the southern skies. A total of 2637 hot objects have been identified using follow-up photometry and spectroscopy of lists of candidates culled from *U* and *B* Schmidt photographic plates. A significant body of work in the broad area of hot stellar astrophysics has resulted, including the discovery of a new type of pulsating hot star.

Although in many ways the detection technique employed is outdated we would argue that this legacy photographic survey has a place amongst the various modern digital optical sky surveys that have been undertaken recently or that are currently underway. A key feature is of course *U*-band coverage on which less emphasis is placed nowadays as sky surveys probe the fainter and redder Universe. For example PanSTARRS (Kaiser et al. 2010) in the Northern hemisphere does not employ a *U* filter although the stunningly successful Sloan Digital Sky Survey does (SDSS; Alam et al. 2015). SDSS has produced a large output of hot star research papers – concerning white dwarfs in particular (e.g. Fusillo et al. 2015; Koester & Kepler 2015) – and largely supersedes the PG survey (Green et al. 1986) which was the previous benchmark in panoramic blue stellar surveys.

Inevitably, the Southern hemisphere EC survey will also be superseded by state-of-the-art CCD-based surveys. For example, SkyMapper (Keller et al. 2007) and VST-ATLAS (Shanks et al. 2013) are current wide–angle photometric surveys of the southern skies, although the latter at least will not cover as large an area of sky. However, we note that the very sensitive modern surveys often have a saturation limit around 15th magnitude so the older and less sensitive photographic surveys are, from this consideration at least, complementary. Furthermore, samples of brighter stars are more amenable to highly detailed follow-up as demonstrated, for example, by the exploitation described in the introduction to this paper. We anticipate that the EC survey will continue to provide astrophysically interesting and exotic examples of hot stars for some time to come.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Table 3. Hot objects in Zones 4–6 of the EC survey.
Table 4. Late-type stars in Zones 4–6 of the EC survey.
(http://www.mnras.oxfordjournals.org/lookup/suppl/doi:10.1093/mnras/stw916/-/DC1).

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